REPORT-IN-PROGRESS

Report 2:

RANKING PLANT SPECIES BY FLAMMABILITY IN THE SOUTHERN UNITED STATES

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Ranking Plant Species by Flammability in the Southern United States

Introduction

Landowners in the wildland-urban interface are routinely advised on 'fire-safe' landscaping techniques in the context of defensible space and fuel reduction. Common recommendations include reducing the number of flammable plants on their property and planting species that are less flammable. However, lists given to homeowners frequently have an unknown origin (Frommer and Weise 1995, University of California FPL 2001). In many cases, species lists are generated from data originating from widely different ecosystems. Knowledge of the relative flammability of both native and ornamental plants in the southern US would be useful to interface landowners, landscape architects, extension agents, and nurseries. In addition, quantification of flammability characteristics of plants can contribute to the development of more ecosystem-specific models of fire behavior (Hough and Albini 1978).

The flammability of western United States species has been studied in many contexts. In the southern United States, similar studies have focused on flammability characteristics of the gallberry-palmetto fuel complex. This paper attempts to expand the discussion of plant flammability to include other plant species in the southern United States that may contribute to fire behavior in the wildland-urban interface. At this time, a comprehensive ranking of flammability is not possible although some comparisons can be made.

Flammability is influenced by many intrinsic and structural characteristics that can be measured in different ways. Flammability of a plant is also influenced by external characteristics such as weather, climate, and location. Flammability studies on southeastern species are reviewed in this report after first introducing the concept of flammability and the characteristics that influence it.

Definition of Flammability

Flammability was initially defined in three components: ignitability, sustainability, and combustibility (Anderson 1970). The ignitability component is the time until ignition once exposed to a heat source. Sustainability is the stability of burning rate, or the ability to sustain fire once ignited. Combustibility is defined as the rate of burn after ignition. The definition of flammability has since been expanded to include consumability, the proportion of mass or volume consumed by fire (Martin et al. 1994).

Anderson (1970) related the flammability components of individual plants to fire characteristics at an ecosystem level. Ignitability of individual plants drives the chain of ignition in an ecosystem. Sustainability is related to the rate of fire spread and combustibility to fire intensity. The consumability of individual plants is analogous with the amount of fuel available for fire consumption on the ecosystem level (Martin et al. 1994). Flammability is a function of plant structure and chemical composition. In this paper, we review flammability at three scales: particle flammability, branch flammability, and plant flammability.

Particle Flammability

Particle level flammability is determined by reducing plant material, typically leaves, into a fine, uniform substance. This method eliminates the influence of structure and is used to study the intrinsic components of flammability. Measurements at this level have been made by thermal evolution analysis (Shafizadeh et al. 1977), oxygen bomb calorimetry (Dickinson and Kirkpatrick 1985, Van Wilgen et al. 1990, Rodríguez-Añón et al. 1995, Núñex-Regueira et al. 2000, Núñex-Regueira et al. 2001, Williamson and Agee 2002), thermogravimetric analysis (Mutch and Philpot 1970, Philpot 1970, Shafizadeh et al. 1977, Gill et al. 1978, Rogers et al. 1986), thermocouple analysis (Owens et al. 1998), and evolved gas analysis (Susott 1982). Major influences on particle flammability are moisture content, percent cellulose, hemicellulose, and lignin, volatile concentration, and silica-free mineral content.

Moisture content highly influences flammability of many materials, including plants. Moisture content was highly significant in the ignition time, maximum burning rate, period of flaming combustion, and flame length of leaf material from *Themeda australis*, *Eucalyptus viminalis*, and *Xanthorrhoea australis* (Gill et al. 1978). However, living fuels in the palmetto-gallberry fuel complex will burn at moisture levels of 100% or more, while dead fuels may not burn at moisture levels of 20-30%; similar observations have been made in southwest chaparral ecosystems and coniferous forests throughout the U.S (Rothermel 1976). Such observations demonstrate that other factors can influence the combustion of vegetation beyond moisture content (1976).

Due to their different chemical properties, plant flammability can also be related to the proportion of cellulose, hemicellulose, and lignin in plant tissue (Rundel 1981). Lignin is thermally stable, and it volatilizes slowly with increasing temperatures, losing only 50% of weight at 500 ^{o}C (Philpot 1970). In comparison, hemicellulose undergoes combustion at 250 ^{o}C with complete volatilization at 500 ^{o}C; and cellulose undergoes rapid combustion between 300 and 400 ^{o}C (Philpot 1970). The combustion characteristics of these elements are affected by the presence of organic volatiles, which can be extracted to test their influence on flammability.

Susott (1982) examined 43 samples from different species and locations and found that foliar material combusted more rigorously than woody material. This was attributed to higher lignin-to-cellulose ratio in woody material, as well as higher extractive concentration in foliage (Susott 1982). In a study of *Pseudotsuga menziesii*, *Pinus ponderosa*, *Populus tremuloides*, *Ilex glabra*, *Arctostaphylos totula*, and *Serenoa repens*, ether and benzene-ethanol extractives contributed up to 60% of the heat release of dried, ground foliar samples (Shafizadeh et al. 1977). Concentration of the extractives in tissues was determined to be a useful but not conclusive prediction of heat release (Shafizadeh et al. 1977). Dried foliar samples from species in a flammable fynbos (South African scrubland) ecosystem were found to have higher crude fat content (oils, fats, waxes, and terpenes) and higher energy content than dried foliar samples from species in a non-flammable forest ecosystem (Van Wilgen et al. 1990). Higher crude fat content, lower foliar moisture content, and higher energy content for fynbos species were thought to contribute, along with structural characteristics of the ecosystems, to the differences in ecosystem flammability (Van Wilgen et al. 1990).

Collectively, the presence of extractives (flavonoids, waxes, terpenes, oils, and resins) increases ignitability and combustibility. This occurs because they typically undergo combustion at lower temperatures than cellulose and lignin and are highly flammable at high temperatures (Rundel 1981). Owens et al. (1998) concluded that a 1 mg/ dried g increase of limonene in *Juniperus ashei*, increased flammability by as much as 30%. However, the same study determined bornyl acetate was negatively related to flammability, decreasing flammability by 2% with a 1 mg/dried g increase, illustrating that not all extractives increase flammability (Owens et al. 1998).

In an early analysis of the impact of mineral content on flammability, Mutch and Philpot (1970) determined that the silica portion of incombustible mineral ash does not influence plant flammability. Further study of the mineral portion of vegetation revealed that an increase in silica-free ash, as percentage of dry weight, decreased maximum combustion rates and increased residues (Philpot 1970). This indicates that the percent of mineral ash, minus silica, in plant tissue decreased the rate at which the tissue combusted.

In summary, flammability at the particle level is related primarily to moisture content. Shafizadeh et al. (1977) concluded that total extractive content likely affects flammability when it exceeds 25% of oven dry mass. Both extractive and mineral content of plants is species dependent, making these intrinsic flammability characteristics significantly different among species.

Branch Flammability

The arrangement of particles into leaf and stem structure contributes additional factors to plant flammability. Methods for testing flammability at the leaf or stem level include muffle furnace tests (Montgomery and Cheo 1971), cone calorimetry (White et al. 1996), and the limiting oxygen index method (Mak 1988). Leaf thickness, surface area-to-volume ratio, and particle density affect flammability at the leaf and stem level.

Time until ignition at 750 ^{o}C was directly related to thickness of foliar samples from 32 species (Montgomery and Cheo 1971). In the same study, surface area-to-volume ratio was inversely related to ignition time for the same samples (Montgomery and Cheo 1971). Heat transfer, in the form of radiation, conduction, and convection, is affected by surface area. In fuels with high surface area-to-volume ratios, heat is transferred faster to the interior causing more rapid combustion (Rundel 1981). In addition, fuels with higher surface area-to-volume ratios can exhibit more rapid water loss, indirectly increasing flammability (Rundel 1981).

The amount of mass per volume of particles, or particle density, also influences heat transfer, thereby affecting flammability (Rundel 1981). Particle density affects the type of ignition, whether spontaneous (indirect heat source) or pilot-ignited (direct heat source). Lower particle density fine fuels are more likely to spontaneously ignite in the absence of a pilot fire (Brown 1970).

In a study assessing the use of the limiting oxygen index method in measuring foliar flammability, mature leaves and freshly fallen leaves from 10 tree and shrub species were tested (Mak 1988). Results showed that the freshly fallen leaves required less oxygen to ignite and sustain burning than the mature leaves of the same plant (Mak 1988). It is unclear how the chemical makeup of the leaves differed. In general, a leaf attached to a plant contributes to fire behavior differently than a similar leaf immediately after being dropped from a plant.

Plant Flammability

Horizontal and vertical arrangement of leaves and branches on a plant can affect its flammability. Measurements of flammability at this scale have been done with an intermediate scale biomass calorimeter with a line burner, which is able to measure the heat released from the combustion of an entire plant (Etlinger 2000). To distinguish which plant characteristics at this level were most significant to plant flammability, Etlinger (2000) recorded percent mass in foliage, foliage moisture content, foliage density, foliage surface area-to-volume ratio, average height, bulk density, packing ratio (bulk density/total particle density), foliage volatiles content, foliage extractives content, and foliage ash content for six shrub species. Regression analysis using all ten independent variables in the comparison of predicted to actual peak heat release rate had an R^2 value of 0.7601 (Etlinger 2000). However, predictions of peak heat release rate using only the mass and moisture content of foliage produced similar results (R^2 of 0.723), indicating that those two variables are the most important predictors of flammability (Etlinger 2000).

In the absence of a quantitative measurement of flammability, five Mediterranean shrubs were compared by their potential fire risk (Papió and Trabaud 1990). Surface area-to-volume ratio and specific gravity were calculated for leaves or spines and stems separately, with stems divided further into live or dead and smaller or larger than 2.5 mm in diameter (Papió and Trabaud 1990). Structural differences were present between species allowing the authors to predict the flammability of species based entirely on the physical characteristics and mass of different plant parts.

External Factors

Climate and weather influence flammability characteristics of plants and related fire behavior, primarily through effects on plant moisture (Agee et al. 2002). Because of this, the location of species in terms of geographical region and location in a landscape can influence plant flammability. Time to ignition for *Juniperus pinchotii* foliage was dependant on the moisture content of the foliage as well as the average daily mean temperature for the month preceding sampling (Bunting et al. 1983). Seasonality and location had a significant effect on the monoterpenoid content, % burned, caloric content, and % moisture content of *Juniperus ashei* foliage (Owens et al 1998). Low temperature volatiles (up to 300 ^{o}C) do not fluctuate seasonally in saw palmetto, gallberry, or wax myrtle (Burgan and Susott 1991). However, there is a seasonal trend in high temperature volatiles (500 ^{o}C) in saw palmetto, wax myrtle, and especially gallberry (Burgan and Susott 1991).

In addition to weather and climate, disturbance may also influence flammability. Fire disturbance can affect moisture content, relative basal area growth rate, and carbohydrate concentration of chestnut oak, scarlet oak, and red maple (Rieske et al.

2002). Fire affected the moisture content and crude fiber content of *Kalmia latifolia* leaves, but not ash content, when compared to unburned plots (Thankston et al. 1982). Percent cover, stem height, leaf area, and specific leaf area of *Kalmia angustifolia*, an ericaceous shrub of Newfoundland, were dependent upon forest type and disturbance regime (Mallik 1994).

Comparing Flammability in the southeastern United States

There have been several studies that have compared the overall flammability of different plants, but few have included southern species. However, data that has been collected are summarized in Table 2 and Table 3. Results from studies examining the flammability of any species in the southeastern US (Table 2) as well as results from various studies, which includes quantification of flammability characteristics (Table 3), are found in the Appendix.

Longleaf pine needles burn faster and more intensely than needles from South Florida slash pine although both are highly flammable (Fonda 2001). Sand pine needles had a significantly longer flame time than longleaf or South Florida slash, but were generally less flammable (Fonda 2001). Longleaf pine litter produces slightly more energy per weight than slash pine litter possibly due to lower mineral content and higher surface area-to-volume ratio for longleaf pine litter (Hough and Albini 1978). No more distinctions between pines can be made at this time, although the observed energy content of the evergreen *Juniperus ashei* (2.6 $kcal \cdot g^{-1}$) was much lower than other evergreen species that have been studied (Owens et al. 1998).

Fuel characteristics of saw palmetto and gallberry are the most extensively studied in the southeast. The flammability characteristics of both species can be compared, because they have been examined in the same studies. For the chemical characteristics, gallberry appears to be more flammable than saw palmetto (Table 1.).

Table 1. Comparable energy content ($kcal \cdot g^{-1}$) data from [a]Shafizadeh et al. (1977) and [b]Hough and Albini (1978).

Species	Green foliage [a]	Live foliage and live stems < ¼" [b]	Live foliage [b]	Live stem ¼ - 1" [b]
Gallberry	3.7	4.68	4.91	4.64
Saw palmetto	2.5	4.51	4.50	4.31

This is confirmed in a comparison of flammability characteristics for saw palmetto, gallberry, and wax myrtle (Burgan and Susott 1991) for which data values are not known. Combusted at temperatures ranging from 300^oC to 500^oC, gallberry burned the most intensely, followed by saw palmetto and then wax myrtle (Burgan and Susott 1991). Gallberry has a very high volatile extractive content (Shafizadeh et al. 1977, Burgan and Susott 1991), which contributes greatly to combustion (Shafizadeh et al. 1977). In contrast, saw palmetto has a low volatile extractive content, so combustion can be attributed to unextractable components such as lignin and cellulose (Shafizadeh et al. 1977). Bark, terminal branch, and foliage of melaleuca has greater energy content

(5.621, 4.585, and 5.146 kcal·g^{-1}) than bark, terminal branch, and foliage of eucalyptus (4.009, 4.497, and 4.894 kcal·g^{-1}) (Wang and Huffman 1982). Melaleuca and eucalyptus are exotics from Australia found in South Florida.

Data on other southern species are much more limited. Based on reported specific leaf area (leaf area per mass), red maple foliage is more flammable than chestnut oak followed by scarlet oak (Rieske et al. 2002). However, the information for these species was not gathered in order to quantify flammability and other information on flammability characteristics is not available. In addition, flammability comparisons between species from different studies are difficult due to differences in environmental conditions and culture methods. Although leaf area per plant was measured for mountain laurel (Thackston et al. 1982) and rosebay rhododendron (Starrett et al. 1993), they are not comparable due to different culture methods of nursery plants. The lack of studies comparing flammability characteristics among species precludes any further comments concerning other fuel components of the south.

Southern species of interest, in terms flammability characteristics, are listed in the Appendix and were the basis for the literature search for this report. A flammability study is currently underway, with funding from the USDA Forest Service Southern Research Station, which will help to expand this list further and gather more information concerning these species of interest. Data from the former USDA Fire Laboratory in Macon, Georgia could be of use in the ranking of southern plant species. These sources will be further explored as the project progresses.

Conclusions and Recommendations

Flammability can be defined as the ignitibility, sustainability, combustibility (Anderson 1970), and consumability (Martin et al. 1994). There are many chemical and structural characteristics that affect flammability at the particle, branch, and plant level. Measurements of flammability are complex, as they include both internal and external properties, and they can be made using a variety of techniques and equipment. In addition, many studies measure only a few characteristics of flammability or focus on only limited plant components, such as leaves. The characteristics of plants that have the greatest influence on flammability appear to be the amount of fine fuels on a plant and the fine fuel moisture content (Etlinger 2000). However, plants with high concentration of organic volatiles can be highly flammable even with high moisture content (Rothermel 1976, Shafizadeh et al. 1977).

Comprehensive rankings of species based on relative flammability cannot be made at this time. A summary of our current state of knowledge follows. Longleaf pine needles and South Florida pine needles are more flammable than sand pine needles (Fonda 2001). Longleaf litter is more flammable than slash pine litter (Hough and Albini 1978). Ashe juniper had relatively low energy content (Owens et al. 1998) when compared to other evergreen species (Table 2 .). Three important southern rough species can be ranked by their flammability as follows (from low to high): wax myrtle, saw palmetto, and gallberry (Shafizadeh et al. 1977, Hough and Albini 1978). Elevated organic volatile content probably contributes to the flammability ofn gallberry (Shafizadeh et al. 1997, Burgan and Susott 1991).

To be able to rank the relative flammability of southern species, more empirical data must be collected. An accepted methodology is necessary for determining the flammability value of plants that incorporates the entire plant structure, but measures only the most influential characteristics (Frommer and Weise 1995, University of California FPL 2001). One approach to ranking flammability of southern species would be to first separate the South into smaller regions with similar climate. Next, a list of important fuel components and native landscape plant species should be compiled for each region. Using standardized methodology to measure important flammability components, such as moisture content and percent fine fuels, species in each region could be compared to one another. The most important time to measure the characteristics is during the typical fire season for the area. Relative flammability rankings for each region in the southern United States could be developed for regional distribution. In addition, results could be compared between the regions in the South, if research methodologies are consistent.

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Appendix

Table 2. Summary of results from studies quantifying flammability of southeastern species.

Species	Component	Author	Location	Energy Content	Consum-mability	Peak temperature	Max. flame height	Flame time; Ember time; Burn time	Mean rate of weight loss (mg/sec)
Gallberry *Ilex glabra*	Green foliage	Shafizadeh et al. 1977	Unknown, supplied by USDA Northern Forest Fire Lab	~3.7 $kcal \cdot g^{-1}$ @500^oC					
Saw palmetto *Serenoa repens*	Green foliage	Shafizadeh et al. 1977	Unknown, supplied by USDA Northern Forest Fire Lab	~2.5 $kcal \cdot g^{-1}$ @500^oC					
Gallberry *Ilex glabra*	Live foliage and stems <1/4"	Hough and Albini 1978	unknown	8430 BTU/lb (4.68 $kcal \cdot g^{-1}$)					
Gallberry *Ilex glabra*	Live foliage	Hough and Albini 1978	unknown	8843 BTU/lb (4.91 $kcal \cdot g^{-1}$)					
Gallberry *Ilex glabra*	Live stem ¼-1"	Hough and Albini 1978	unknown	8350 BTU/lb (4.64 $kcal \cdot g^{-1}$)					
Gallberry *Ilex glabra*	Dead stem <1/4"	Hough and Albini 1978	unknown	8270 BTU/lb (4.59 $kcal \cdot g^{-1}$)					
Saw palmetto *Serenoa repens*	Foliage and stems <1/4"	Hough and Albini 1978	unknown	8122 BTU/lb (4.51 $kcal \cdot g^{-1}$)					
Saw palmetto *Serenoa repens*	Live foliage	Hough and Albini 1978	unknown	8100 BTU/lb (4.50 $kcal \cdot g^{-1}$)					
Saw palmetto *Serenoa repens*	Live stem ¼-1"	Hough and Albini 1978	unknown	7767 BTU/lb (4.31 $kcal \cdot g^{-1}$)					
Saw palmetto *Serenoa repens*	Dead foliage	Hough and Albini 1978	unknown	8408 BTU/lb (4.67 $kcal \cdot g^{-1}$)					
Slash pine *Pinus elliottii*	Litter (L&F)** <1/4"	Hough and Albini 1978	unknown	8592 BTU/lb (4.77 $kcal \cdot g^{-1}$)					
Slash pine	Litter (L)	Hough and	unknown	8753 BTU/lb					

Pinus elliottii	foliage	Albini 1978		(4.86 kcal·g^{-1})					
Species	Component	Author	Location	Energy Content	Consum-mability	Peak temperature	Max. flame height	Flame time; Ember time; Burn time	Mean rate of weight loss (mg/sec)
Slash pine *Pinus elliottii*	Litter (F) foliage	Hough and Albini 1978	unknown	8498 BTU/lb (4.72 kcal·g^{-1})					
Slash pine *Pinus elliottii*	Litter ¼-1"	Hough and Albini 1978	unknown	8393 BTU/lb (4.66 kcal·g^{-1})					
Slash pine *Pinus elliottii*	Litter 1-3"	Hough and Albini 1978	unknown	8057 BTU/lb (4.48 kcal·g^{-1})					
Slash pine *Pinus elliottii*	Litter (H) <1/4"	Hough and Albini 1978	unknown	7878 BTU/lb (4.38 kcal·g^{-1})					
Longleaf pine *Pinus palustris*	Litter (L&F) <1/4"	Hough and Albini 1978	unknown	8757 BTU/lb (4.86 kcal·g^{-1})					
Longleaf pine *Pinus palustris*	Litter (H) <1/4"	Hough and Albini 1978	unknown	8031 BTU/lb (4.46 kcal·g^{-1})					
Longleaf pine *Pinus palustris*	Needles	Fonda 2001	Ocala National Forest, FL		91.9		82.3 cm	87.7; 140.2; 228.6	62.2 mg/sec
South Florida slash pine *Pinus elliottii* var. *densa*	Needles	Fonda 2001	Archbold Station, Lake Placid, FL		90.8		71.2 cm	90.1; 290.0; 380.2	36.7 mg/sec
Sand pine *Pinus clausa*	Needles	Fonda 2001	Ocala National Forest, FL		61.6		50.3 cm	195.4; 124.6; 319.9	29.1 mg/sec
Ashe juniper *Juniperus ashei*	Mature foliage and small stems	Owens et al. 1998	Sonora Research Station, TX Annadale Ranch, TX	2.6 kcal·g^{-1}	Ave. 78.8 of fresh foliage (50 to 90% based on season)	450-500^{o}C			
Melaleuca *Melaleuca quinquenervia*	Bark; Terminal Branch; Foliage	Wang and Huffman 1982	Southern Florida	5.621 kcal·g^{-1}***; 4.585 kcal·g^{-1}; 5.146 kcal·g^{-1}					
Eucalyptus *Eucalyptus grandis*	Bark; Terminal Branch; Foliage	Wang and Huffman 1982	Southern Florida	4.009 kcal·g^{-1}; 4.497 kcal·g^{-1}; 4.894 kcal·g^{-1}					

* Originally reported only in BTU/lb; conversion made by 0.251996 kcal/1 BTU and 1 lb./453.6g.

** (L), (F), and (H) are not defined in Hough and Albini 1978

*** Originally reported in cal·g^{-1}; conversion made by 1 kcal/1000 cal

Table 3. Summary of results from studies quantifying characteristics of flammability for southeastern species.

Species	Component	Author	Location	Extractive concentration	Particle density	Mineral content; Effective mineral content (silica-free)	Surface area/volume	Leaves	Ash content
Ashe juniper *Juniperus ashei*	Mature foliage and small stems	Owens et al. 1998	Sonora Research Station, TX Annadale Ranch, TX	(monoterpenoid) 9.16 $mg{\cdot}g^{-1}$ to 11.92 $mg{\cdot}g^{-1}$					
Gallberry *Ilex glabra*	Live foliage	Shafizadeh et al. 1977	Unknown, supplied by USDA Northen Forest Fire Lab	44.6%					
Saw palmetto *Serenoa repens*	Live foliage	Shafizadeh et al. 1977	Unknown, supplied by USDA Northen Forest Fire Lab	13.1%					
Saw palmetto *Serenoa repens*	Foliage and stems <1/4”	Hough and Albini 1978	unknown		50.3 lb/ft^3	0.047 lb/lb			
Saw palmetto *Serenoa repens*	Live foliage	Hough and Albini 1978	unknown		50.1 lb/ft^3	0.034 lb/lb	2196 ft^2/ft^3		
Saw palmetto *Serenoa repens*	Live stem <1/4”	Hough and Albini 1978	unknown		53.9 lb/ft^3		409 ft^2/ft^3		
Saw palmetto *Serenoa repens*	Live stem ¼-1”	Hough and Albini 1978	unknown		54.7 lb/ft^3	0.021; 0.15 lb/lb	238 ft^2/ft^3		
Saw palmetto *Serenoa repens*	Dead foliage	Hough and Albini 1978	unknown		31.6 lb/ft^3		1994 ft^2/ft^3		
Saw palmetto *Serenoa repens*	Dead stem <1/4”	Hough and Albini 1978	unknown		27.9 lb/ft^3		263 ft^2/ft^3		
Saw palmetto *Serenoa repens*	Dead stem ¼-1”	Hough and Albini 1978	unknown		28.4 lb/ft^3		169 ft^2/ft^3		
Gallberry *Ilex glabra*	Live foliage and stems <1/4”	Hough and Albini 1978	unknown		43.8 lb/ft^3	0.023; 0.02 lb/lb			
Gallberry *Ilex glabra*	Live foliage	Hough and Albini 1978	unknown		37.4 lb/ft^3	0.021 lb/lb	2593 ft^2/ft^3		

Species	Component	Author	Location	Extractive concentration	Particle density	Mineral content; Effective mineral content (silica-free)	Surface area/volume	Leaves	Ash content
Gallberry *Ilex glabra*	Live stem <1/4"	Hough and Albini 1978	unknown		47.0 lb/ft^3		447 ft^2/ft^3		
Gallberry *Ilex glabra*	Live stem ¼-1"	Hough and Albini 1978	unknown		44.1 lb/ft^3	0.013; 0.10 lb/lb	141 ft^2/ft^3		
Gallberry *Ilex glabra*	Dead foliage	Hough and Albini 1978	unknown						
Gallberry *Ilex glabra*	Dead stem <1/4"	Hough and Albini 1978	unknown		39.8 lb/ft^3	0.014; 0.09 lb/lb	404 ft^2/ft^3		
Gallberry *Ilex glabra*	Dead stem ¼-1"	Hough and Albini 1978	unknown		38.4 lb/ft^3		136 ft^2/ft^3		
Slash pine *Pinus elliottii*	Litter (L&F) <1/4"	Hough and Albini 1978	unknown		30.4 lb/ft^3	0.036; 0.012 lb/lb	1729 ft^2/ft^3		
Slash pine *Pinus elliottii*	Litter (L) foliage	Hough and Albini 1978	unknown			0.021 lb/lb	1883 ft^2/ft^3		
Slash pine *Pinus elliottii*	Litter (F) foliage	Hough and Albini 1978	unknown			0.028 lb/lb	1900 ft^2/ft^3		
Slash pine *Pinus elliottii*	Litter ¼-1"	Hough and Albini 1978	unknown		27 lb/ft^3	0.018; 0.011 lb/lb	107 ft^2/ft^3		
Slash pine *Pinus elliottii*	Litter 1-3"	Hough and Albini 1978	unknown		28.4 lb/ft^3	0.018; 0.008 lb/lb	32 ft^2/ft^3		
Slash pine *Pinus elliottii*	Litter (H) <1/4"	Hough and Albini 1978	unknown		24.5 lb/ft^3	0.098; 0.017 lb/lb			
Longleaf pine *Pinus palustris*	Litter (L&F) <1/4"	Hough and Albini 1978	unknown		31.7 lb/ft^3	0.032; 0.013 lb/lb	1851 ft^2/ft^3		
Longleaf pine *Pinus palustris*	Litter ¼-1"	Hough and Albini 1978	unknown		30.2 lb/ft^3		104 ft^2/ft^3		
Longleaf pine *Pinus palustris*	Litter 1-3"	Hough and Albini 1978	unknown		32.5 lb/ft^3		19 ft^2/ft^3		
Longleaf pine *Pinus palustris*	Litter (H) <1/4"	Hough and Albini 1978	unknown		25.0 lb/ft^3	0.082; 0.013 lb/lb			
Chestnut oak *Quercus pinus*	Live foliage	Rieske et al. 2002	Daniel Boone National Forest, KY					203.53 $cm^2 \cdot g^{-1}$	
Scarlet oak *Quercus coccinea*	Live foliage	Rieske et al. 2002	Daniel Boone National Forest, KY					167.92 $cm^2 \cdot g^{-1}$	
Red maple *Acer rubrum*	Live foliage	Rieske et al. 2002	Daniel Boone National Forest, KY					214.65 $cm^2 \cdot g^{-1}$	

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Species	Component	Author	Location	Extractive concentration	Particle density	Mineral content; Effective mineral content (silica-free)	Surface area/volume	Leaves	Ash content
Mountain laurel *Kalmia latifolia*	Dried leaves	Thackston et al. 1982	Chattahoochee National Forest, GA						3.6%
Mountain laurel *Kalmia latifolia* cultivars	Leaves	Brand 1997	Cultured at University of Connecticut					1188-3248 cm^2 per plant; 20-82 g dry wt. per plant	
Rosebay rhododendron *Rhododenron maximum*	Leaves	Starrett et al. 1993	Cultured in Tennessee					70-85 cm^2 per leaf; 300-450 cm^2 per plant	
Brazilian pepper tree *Schinus terebenthfolius*	Fresh leaves	Saleh 1988	Egypt	15.6 g essential oil per kg fresh weight					
Melaleuca *Melaleuca qiunquenervia*	Bark; Terminal Branch; Foliage	Wang and Huffman 1982	Southern Florida	21.10 %; 9.06 %; 26.82 %					
Eucalyptus *Eucalyptus grandis*	Bark; Terminal Branch; Foliage	Wang and Huffman 1982	Southern Florida	15.36 %; 12.94 %; 32.88 %					

Southern Plant Species for Flammability Lists

Brazilian Pepper (*Schinus terebinthifolius*)
Common Reed (*Phragmites australis*)
Gallberry (*Ilex glabra*)
Kudzu (*Pueraria lobata*)
Laurel oak (*Quercus laurifolia*)
Melaleuca (*Melaleuca quinquenervia*)
Mountain laurel *(Kalmia latifolia*)
Pinehill bluestem (*Schizachyrium scoparium* var. *divergens*)
Rosebay rhododendron (*Rhododendron maximum* L.)
Saw palmetto (*Serenoa repens*)
Smilax (*Smilax* spp.)
Titi (*Cliftonia monophylla*)
Wax myrtle (*Myrica cerifera*)
Wiregrass (*Aristida stricta*)
Switchcane (*Arundinaria tecta*)

Pines:
Shortleaf pine (*Pinus echinata*)
Longleaf pine (*P. palustris*)
Slash pine (*P. elliottii*)
Loblolly pine (*P. taeda*)
Virginia pine (*P. virginiana*)
Pitch pine (*P. rigida*)
Table mountain pine (*P. pungens*)
Pond pine (*P. serotina*)
Sand pine (*P. clausa*)